US ATLAS Upgrade Program

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(for the US ATLAS Collaboration)

P5 Workshop on the Future of High Energy Physics
Brookhaven National Lab
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Outline

- Motivation for Detector Upgrades
  - The LHC Upgrade Schedule
- The ATLAS Upgrade Program
  - brief review of pre-Phase II work
  - Phase II overview
  - Planned US Involvement
- Preliminary Phase-II Schedule, Budget & Effort Estimates
- Impact of Upgrades on US Infrastructure
  - labs, universities, industry
- Conclusions

Upgrade Motivation

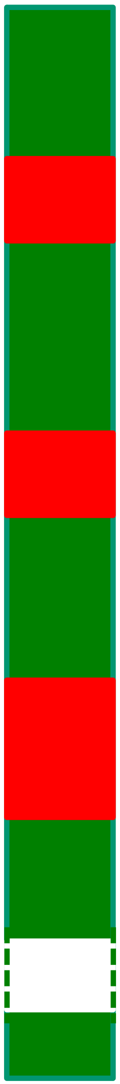
- Physics driven by response to rising luminosity
  - Higher Rates ==> Trigger (mod's to Tracker, Calorimeters, Muon Systems)
    - retain efficient triggers on single leptons with p_T ~ 20 GeV
  - Complex Events (pileup) ==> Tracking (+ Trigger)
    - vertex reconstruction (primary & secondary)
    - tracking in the core of high E_T jets
    - missing E_T

- Detector performance degradation
  - Performance at High Luminosity
    - Much higher data rates/volumes ==> readout
    - Radiation damage ==> silicon, front end electronics
  - Detector Integrity
    - Detector operating since (at least) 2009 ==> component aging & obsolescence

New LHC Timeline

updated by CERN
Dec. 2, 2013

2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027
…
…
2035



Run 1: **$\sqrt{s}$=7-8 TeV**, **∫Ldt=25 fb-1**, pileup **μ≈20**

$L^{peak}=0.7\times10^{34}$ cm^{-2}s^{-1}

LS1: **phase 0** upgrade

Run 2: $\sqrt{s}$≈**13-14 TeV**, **∫Ldt≈120 fb-1**, pileup **μ≈43**

$L^{peak}=1.6\times10^{34}$ cm^{-2}s^{-1}

LS2: **phase 1** upgrade

Run 3: **$\sqrt{s}$≈14 TeV, ∫Ldt≈350 fb-1**, pileup **μ=50-80**

$L^{peak}\approx2\text{-}3\times10^{34}$ cm^{-2}s^{-1}

LS3: **phase 2** upgrade

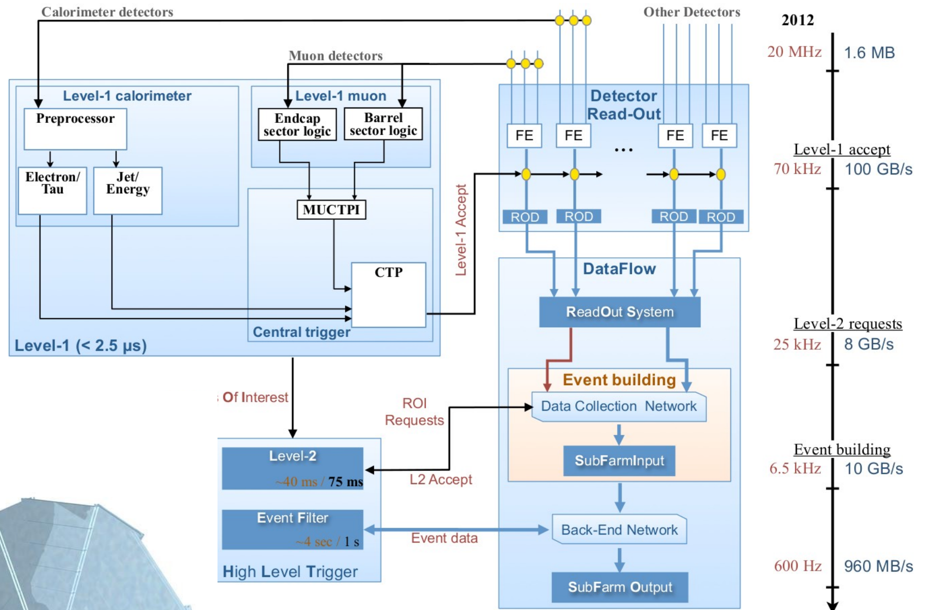
HL-LHC: **$\sqrt{s}$≈14 TeV, ∫Ldt≈3000 fb^{-1}**, pileup **μ≈140-200**

$L^{peak}=20\times10^{34}$ cm^{-2}s^{-1} leveled to $L^{peak}=(5\text{-}7.5)\times10^{34}$ cm^{-2}s^{-1}

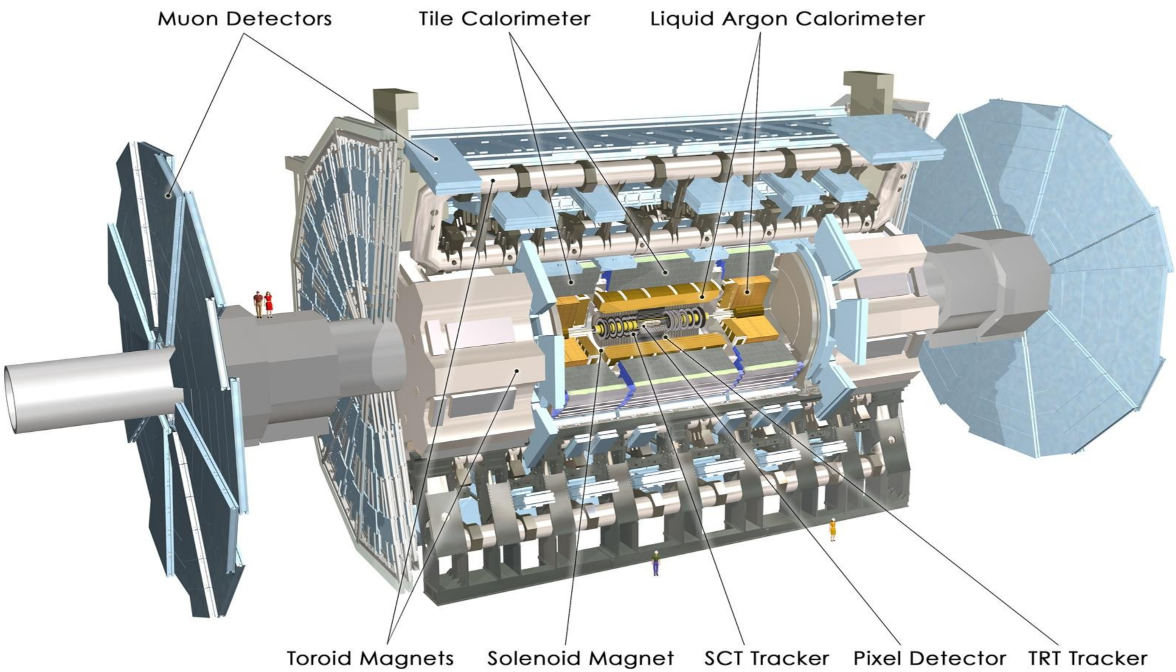
*LS="long shutdown"

ATLAS Detector & Trigger/DAQ

2012 Trigger/DAQ



2012 ATLAS Detector



Rate (kHz)	2012	Phase II
Bunch Crossing	20,000	40,000
L1 Trigger	75	200
to disk	0.4	~10

Run 1 ATLAS Operations

- Very successful runs at 7 TeV (2010-11) and 8 TeV (2012)
  - ATLAS recorded 5.3 fb^{-1} (7 TeV) and 21.7 fb^{-1} (8 TeV)
  - 2012 data-taking efficiency: 93.5% – detector efficiencies: 97-100%
- US played a key role in Original ATLAS Construction and Run 1
  - US ATLAS detector construction cost at CD4B: $165M
    - ~20% of ATLAS "core" costs (no personnel or contingency)

System	Unique US Expertise
Tracking	• Pixels: ICs, mechanics • SCT: mechanics • TRT: modules, electronics
Calorimetry	• LAr: FE electronics, LV power • FCAL • Tile: modules, electronics, LV power
Muons	• Forward: chambers, electronics
TDAQ	• core software, RoIBuilder, Timing

Physicist Activity (2013)	FTE
Ops/Computing	142
Analysis	280
Upgrade R&D	48
Phase-I Construction	14
TOTAL	**484**
Technical Personnel	130

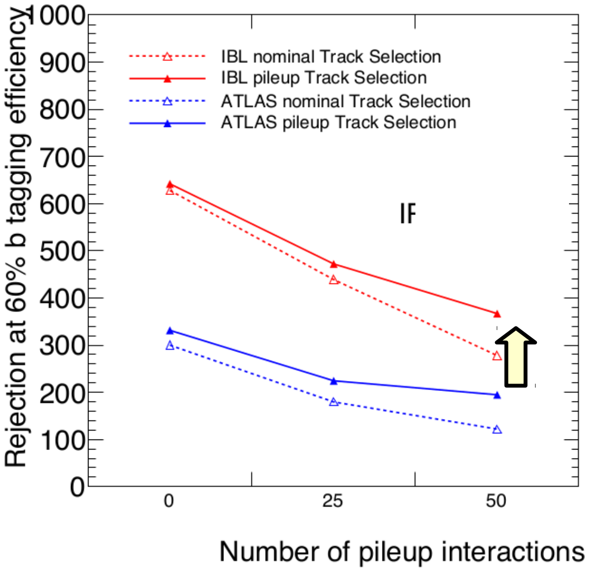
ATLAS Upgrades Overview

System	Phase 0 Upgrades	Phase I Upgrades	Phase II Upgrades
Tracking	• IBL pixels • pixel new services		• replace pixel/SCT/TRT with all-Silicon tracker
LAr Calo	• new LV power supplies	• finer granularity to L1Calo	• full granularity digital readout at 40 MHz to L1Calo • replace forward calorimetry
Tile Calo	• new LV power supplies		• completely replace electronics - digital signals to L1 • improved mechanics
Muons		• NSW endcap muon system	• replace readout electronics - precision (MDT) to L1
TDAQ	• Topology at L1 • Fast TracKer (FTK) at L2 • L2/Evt Filter/Evt Builder on one CPU	• new L1Calo • NSW in L1Muon • continued L2 FTK	• move to L0/L1 architecture • add tracking to L1 (L1Track) • more use of commodity hardware in HLT/DAQ

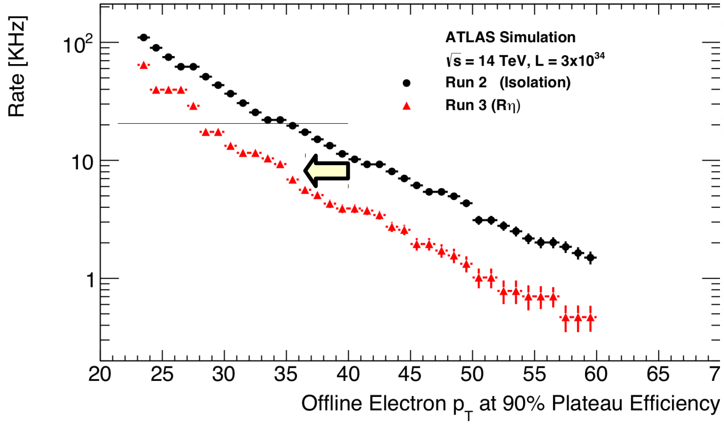
Phase 0/I Upgrades

- Primary challenges motivating upgrades
  - Luminosity 2×10^{34} cm^{-2} s^{-1} at 25 ns bunch crossing
    - ==> 55 pp collisions per bunch crossing (pileup)
    - big effects on: Tracking Efficiency, Trigger (especially single-e/μ)
    - also complicates jet and missing E_T reconstruction
  - Background rate in Forward Muon Trigger System

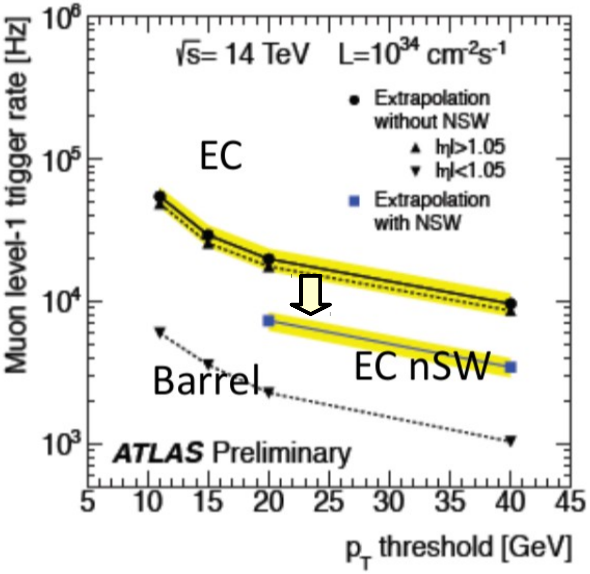
b-tagging with IBL



L1EM Rate vs Threshold



L1Muon Rate vs Threshold



US in Phase 0/I Upgrades

System	Phase	Unique US Responsibilities	Institutes
Tracking (IBL) **[NSF MRI]**	0	• ICs: FE-I4 • optical data transmission • mechanics • readout	Brandeis, Iowa, Ohio, Oklahoma, Oklahoma State, LBNL, SLAC, Stony Brook, UCSC, UNM, Washington
Calorimeter (LAr)	I	• Layer Sum Boards (ADCs, data format, optical xmit) • Low Voltage (regulators and POL convertors) • Back-end hardware and firmware • FCAL Baseplanes	Arizona, BNL, Columbia, Oregon, Penn, Pitt, SMU, Stony Brook
Muons (NSW)	I	• ASICs: FE readout, Trigger Data Serializer • MicroMega Front End Boards • MicroMega Trigger: Address Data Driver, Trigger Processor • Readout: MicroMega readout drivers • Alignment system	Arizona, BNL, Brandeis, Illinois, Michigan, SLAC, UCI
TDAQ	0 0/I I	• L1Calo → L1 Topology Trigger data distribution (CMX board) • L2/EventFilter/EventBuilder merger • FTK (5/9 major components) – **[NSF MRI]** • L1Calo electronics (2/5 boards) & firmware	ANL, BNL, Chicago, Indiana, Illinois, MSU, NIU, Oregon, UCI, SLAC, Wisconsin
Software	0/I	• Very large US effort – but covered from Operations (not Phase I construction)	

US Phase I Upgrade Project

- ❖ The Phase I Upgrade Project
  - first major construction effort of US ATLAS since original detector
- ❖ This initial phase is limited in scope
  - Cost < $46M
    - Total Project Cost (NSF+DOE)
  - over ~5 years
- ❖ Launched under tight time constraints
  - DOE CD-0 approval: Aug. 2011
  - formal project launch: Nov. 2012
  - NSF proposal submitted: Jun. 2013
  - DOE CD-1 approval: Sep. 2013

System	On-proj FTE	CD-1 US Total Cost (AYM$)	CD-1 US Core Cost (AYM$)	ATLAS Core Cost (MCHF)
LAr Calorim	36.6	13.3	3.7	7.6
Muon NSW	51.6	11.8	5.3	11.5
TDAQ	12.5	2.9	0.2	7.8
Management	7.7	4.4		
Contingency		13.7		
TOTAL	**108.4**	**46.0**	**9.2**	**36.0***

* includes FTK, TileCal, Common Costs

- ❖ Phase I upgrade has substantially benefited from Upgrade R&D program
  - funded through US ATLAS Operations program since 2003
- ❖ US recognized to be a strong collaborator on ATLAS
  - proven track record, including construction

Phase II Goals

See ATLAS Phase II LoI for more details: https://cds.cern.ch/record/1502664

❖ Physics

Study EWSB Mechanism	precision meas's of Higgs couplings (5-30%), Higgs self-coupling
Probe for signatures of New Physics	SUSY, Extra Dimensions, ….
Measure Rare Decay Modes	Higgs, B, top, ….

❖ Detector Requirements

Requirement	Example Physics/Detector Motivation
Trigger & Reconstruct low p_T e/μ	complex SUSY cascades
Trigger on τ's	$H \rightarrow \tau\tau$
Good lepton e/μ momentum resolution at high p_T	high-mass gauge bosons
Identify Heavy Flavors	complex SUSY cascades
Reconstruct leptons & b's in boosted topologies	resonances in top pairs, W, Z, H
Preserve acceptance in forward region	VBF, Missing E_T
Radiation Tolerance and Granularity	efficient tracking with small fake rates
Compatibility with new trigger system	impacts Front End electronics
Sufficient Computing & associated software	(but not part of Phase II construction)

US Participation in Phase II

Summary of US Phase II Activities & Institutes

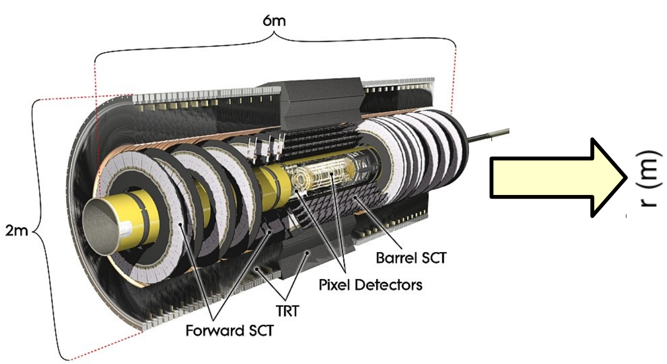
Tracker	• strip & pixel module assembly • strip staves: electronics, mechanics, assembly • pixel readout	BNL, Duke, Iowa, LBNL/Berkeley, Ohio State, Oklahoma, Oklahoma State, Penn, SLAC, UCSC, UNM, Washington, Yale
TDAQ	• L1Track, FTK, L0/L1Calo • DAQ readout system	ANL, BNL, Chicago, Illinois, Indiana, MSU, NIU, Oregon, Penn, SLAC, UCI
LAr	• preamp/shaper, ADC, optical link ASICS • Forward Calorimeter (FCAL)	Arizona, BNL, Columbia, Penn, SMU, Stony Brook
TileCal	• Front End & Main Boards • Low Voltage • Detector Control Systems	ANL, Chicago, MSU, UTA
Muons	• Endcap Chamber Service Modules & cabling • Endcap MDT readout ASIC and mezzanines	Arizona, BNL, Brandeis, BU, Harvard, Michigan, UCI
Software	• Large US effort – not included in Phase II construction	many US institutes

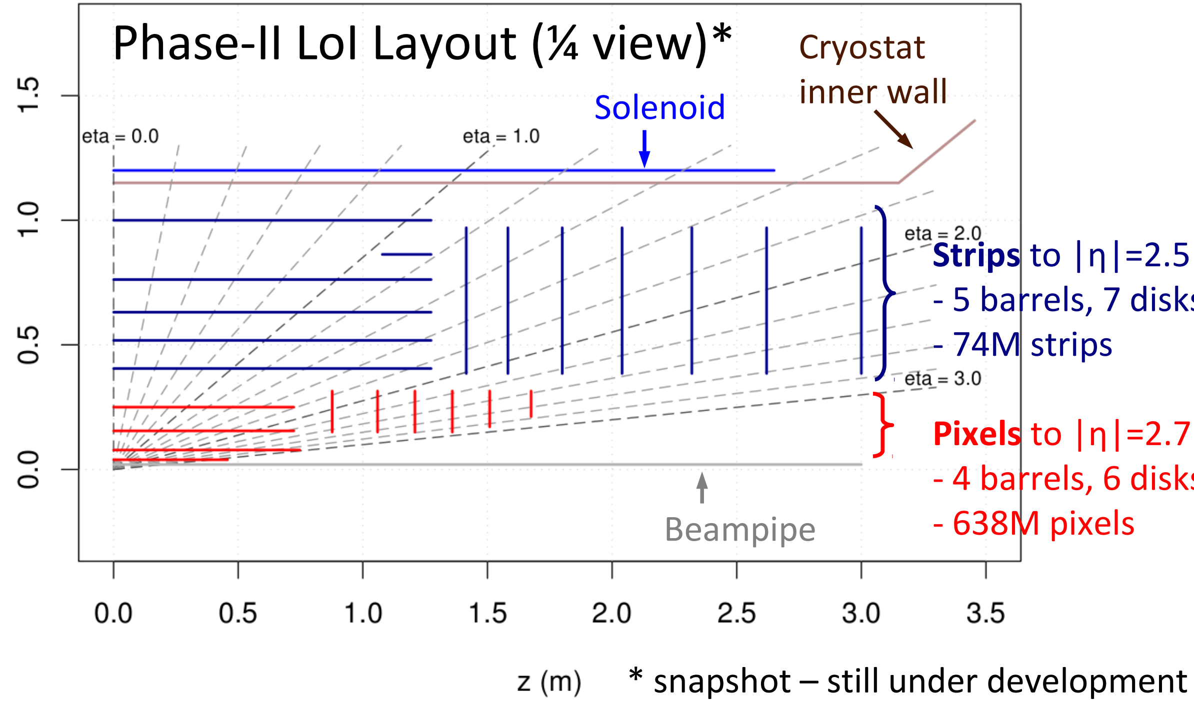
Note: US Phase II Upgrade projects carefully chosen to match unique & specific US expertise

- not proposing many potentially interesting projects where non-US expertise exists

Phase II Tracker

Current ATLAS Tracker



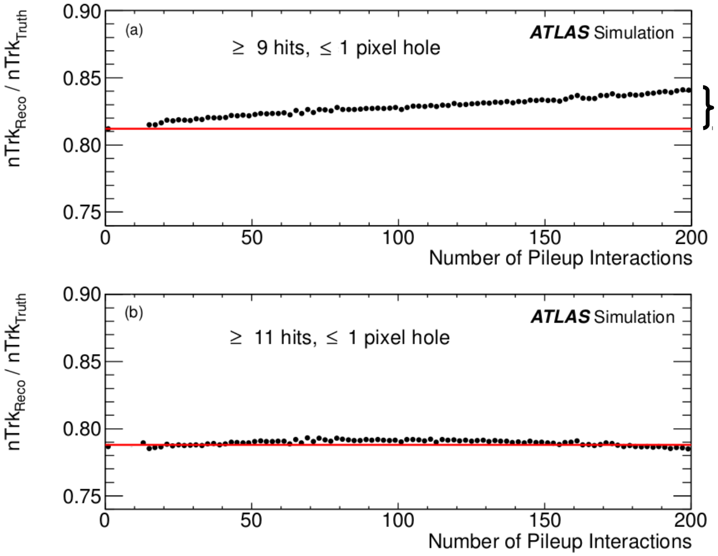


* snapshot – still under development

- Phase-II Tracker Goals
  - Good/Robust Pattern Recognition: 14 meas planes (11 hits/track to reduce fakes)
  - Good Track Location at LAr Calorimeter: 1 mm resolution in z
  - High muon efficiency and resolution: 20% improvement in mass resolution for $H \rightarrow \mu\mu$
  - Efficient b-jet tagging w/ good light-q rejection: factor 400 rejection for 65% efficiency

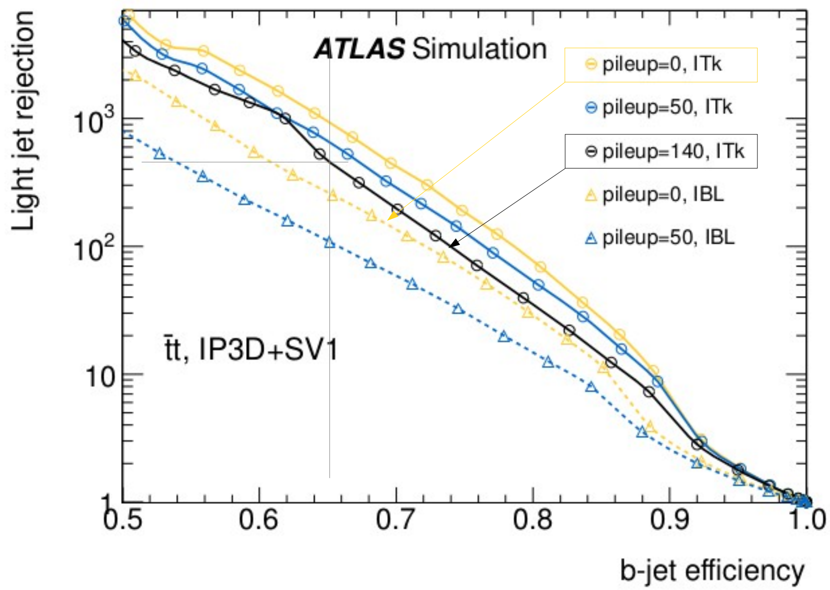
Phase II Tracker: Performance

Fake Rate vs min N_{hits}



} increase in fakes

Light-q Rejection vs b-Tag Efficiency



Track Parameter ($\|\eta\| < 0.5$)	Existing Tracker + IBL	Phase II Tracker
Pileup	0	200
q/p_T [TeV^{-1}]	0.3	0.2
Transverse Impact Param [μm]	8	8
Longitudinal Impact Param [μm]	65	50

Phase II Tracker: US Involvement

Activity	R	U	S	I	Comments
Strip stave mod. assemb.	X		X	X	• long-standing expertise in precision micro-electronic assembly • US would produce 20% of assemblies
Strip staves - Mechanical	X	X	X	X	• world-class expertise in high performance C-based thermo-mech comp's • US industry has unique expertise in bus tapes
Strip staves - Electrical	X			X	• US digital/analog design ==> key circuit components
Strip stave Assembly			X	X	• US would load 50% of staves
Strip/Pixel Readout	X	X		X	• led design of high-speed I/O DAQ architecture
Pixel module r'dout IC	X		X		• joint ATLAS/CMS R&D: US leadership in RD53
Pixel barrel support	X	X	X	X	• unique experience & in-house constr. capability
Pixel module assemb/test			X	X	• many sites world-wide – testing by phys/student
Pixel system integration		X			• build on current pixel expertise/leadership

KEY

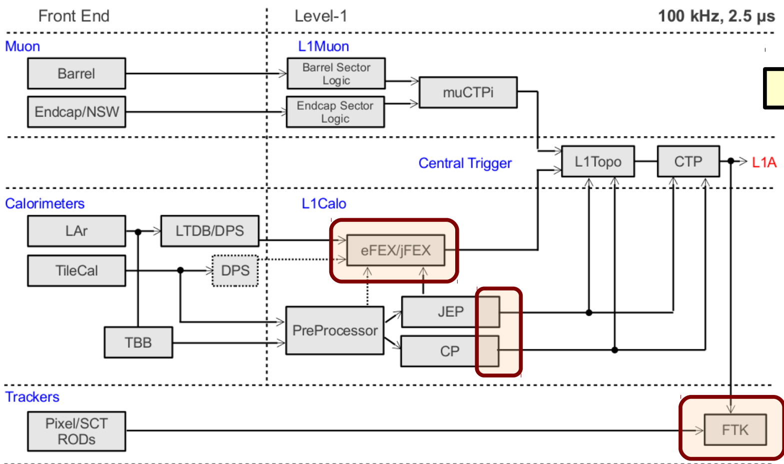
R	R&D	An R&D activity pursued by the US
U	Unique	Unique US project without other collaborators
S	Schedule	A major production activity shared between many ATLAS institutes If the US did not participate it would cause the schedule to slip
I	Infrastructure	An activity that uses significant US-based infrastructure/facilities

* all activities provide valuable training opportunities for students and postdocs

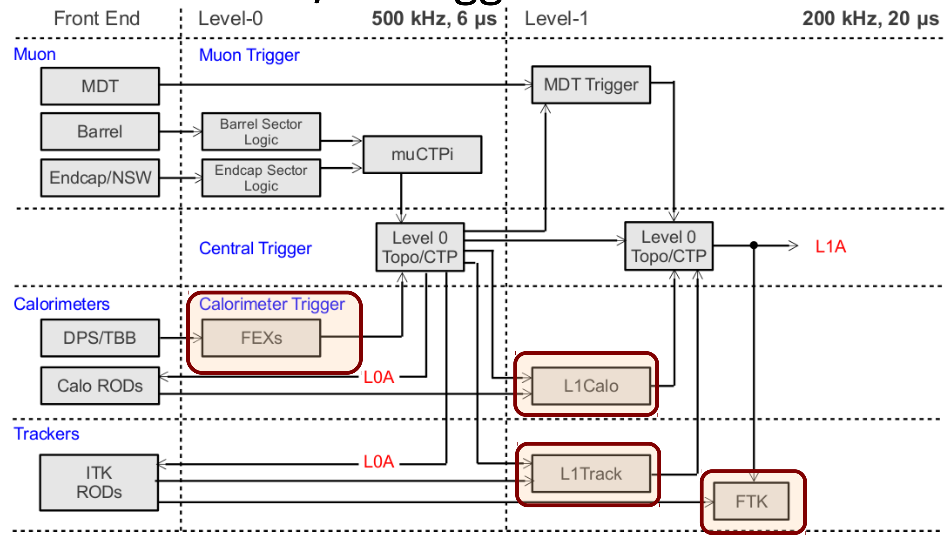
Phase II Trigger/DAQ

Phase I L1 Trigger

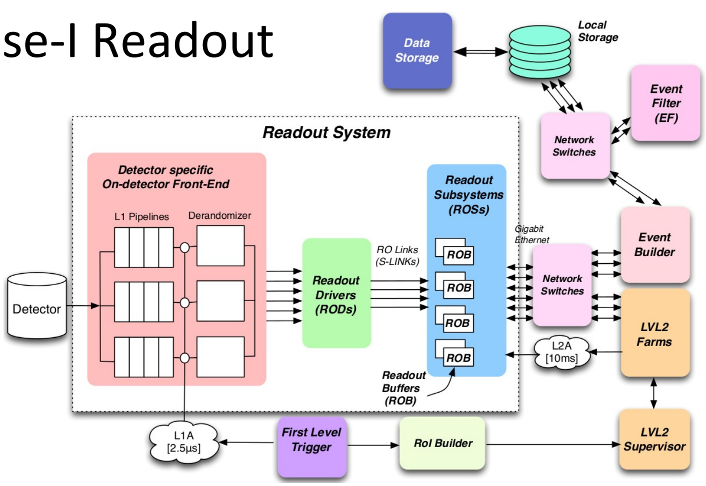
US involvement



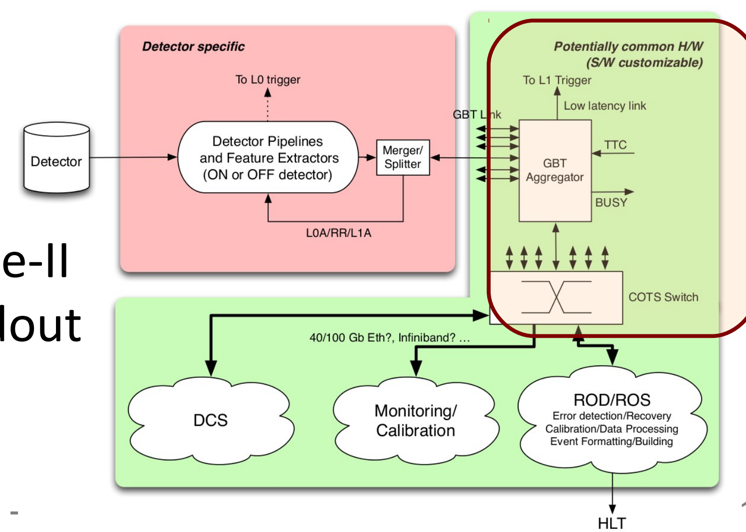
Phase II L0/L1 Trigger



Phase-I Readout



Phase-II Readout

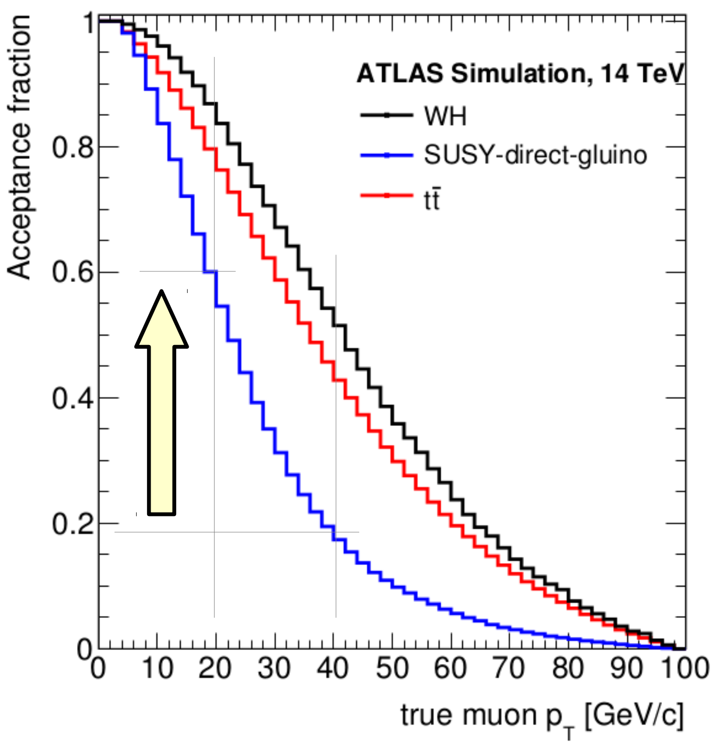


Phase II TDAQ: Goals & Performance

❖ Phase II Trigger/DAQ Goals

- Preserve high eff for Higgs, top, SUSY: L1 p_T for isol e/μ = 20 GeV w/ rate < 40 kHz
- Readout & store data: 4× higher bandwidth than Phase I
- More easily maintain system: common, commercial comp's

~60% of 2013 pub's used single-ℓ triggers



Object(s)	Trigger	Phase I	Phase II
e	EM20	200 kHz	40 kHz
γ	EM40	20 kHz	10 kHz
μ	MU20	>40 kHz	10 kHz
τ	TAU50	50 kHz	20 kHz
ee	2EM10	40 kHz	<1 kHz
γγ	2EM10	as above	~5 kHz
eμ	EM10_MU6	30 kHz	<1 kHz
μμ	2MU10	4 kHz	<1 kHz
ττ	2TAU15I	40 kHz	2 kHz
other	JET+MET	~100 kHz	~100 kHz
Total	**(7×10^{34} cm^{-2} s^{-1})**	**~500 kHz**	**~200 kHz**

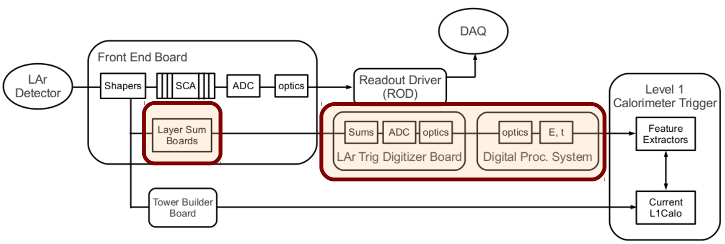
Phase II TDAQ: US Involvement

Activity	R	U	S	I	Comments
L1Track / FTK Upgrade	X	X			• leadership in current FTK ==> strong position for L1Track (considering FTK-like architecture)
L0/L1 Calorimeter		X			• build on US responsibilities for Phase I L1Calo & Phase 0 CMX
Readout	X			X	• leading role in new-generation, ATCA-based DAQ hardware
Core Software					• critical US effort/leadership here • but not part of construction project

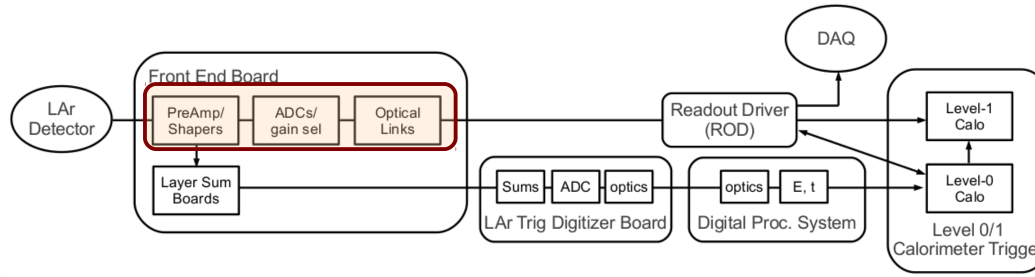
Phase II LAr Calorimeter

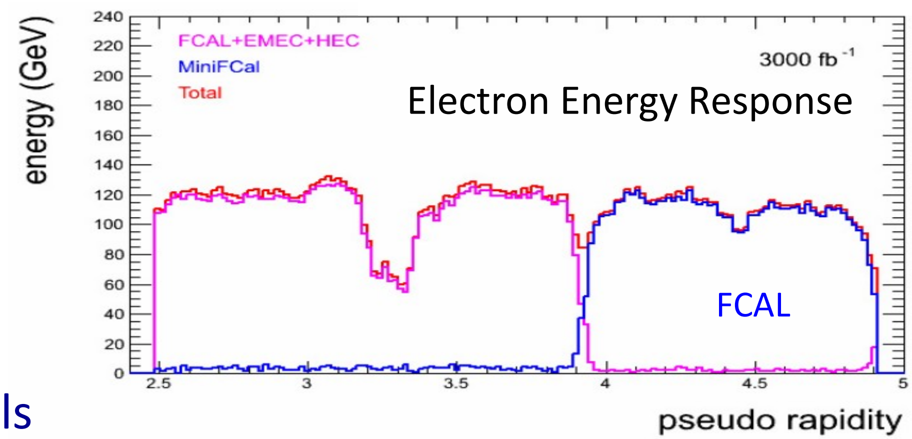
US involvement

LAr Electronics in Phase I



LAr Electronics in Phase II





- Phase II LAr Goals
  - Retain ability to trigger on low p_T e/γ: L0Calo + full granularity input to L1Calo
  - Measure missing E_T at high occupancy: also at trigger
  - More robust/reliable system: increased radiation dose
  - Maintain forward accept. for jet-tagging: new FCAL

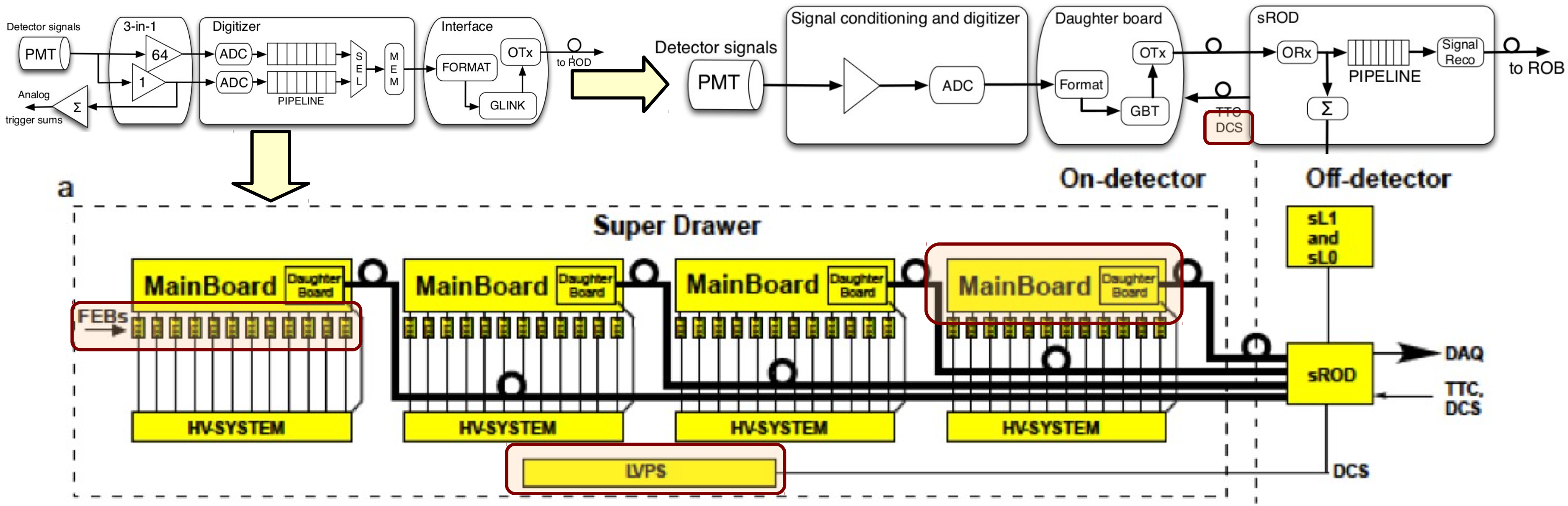
Phase II LAr: US Involvement

Activity	R	U	S	I	Comments
Preamp/Shaper ASIC	X			X	• strong design teams ==> US groups have developed 2 viable designs well ahead of other countries
ADC ASIC	X	X		X	• experience with current FEs & Phase I ADCs ==> US well ahead of competing designs
Optical Link ASICs	X	X		X	• unique expertise in high-speed, rad-hard optical link development
FCAL Construction	X	X		X	• US was primarily responsible for original FCAL • have taken the lead on R&D to determine impact of HL-LHC environment on current FCAL

Phase II Tile Calorimeter

Current TileCal Readout

TileCal Readout in Phase II



US involvement

❖ Phase II TileCal Goals

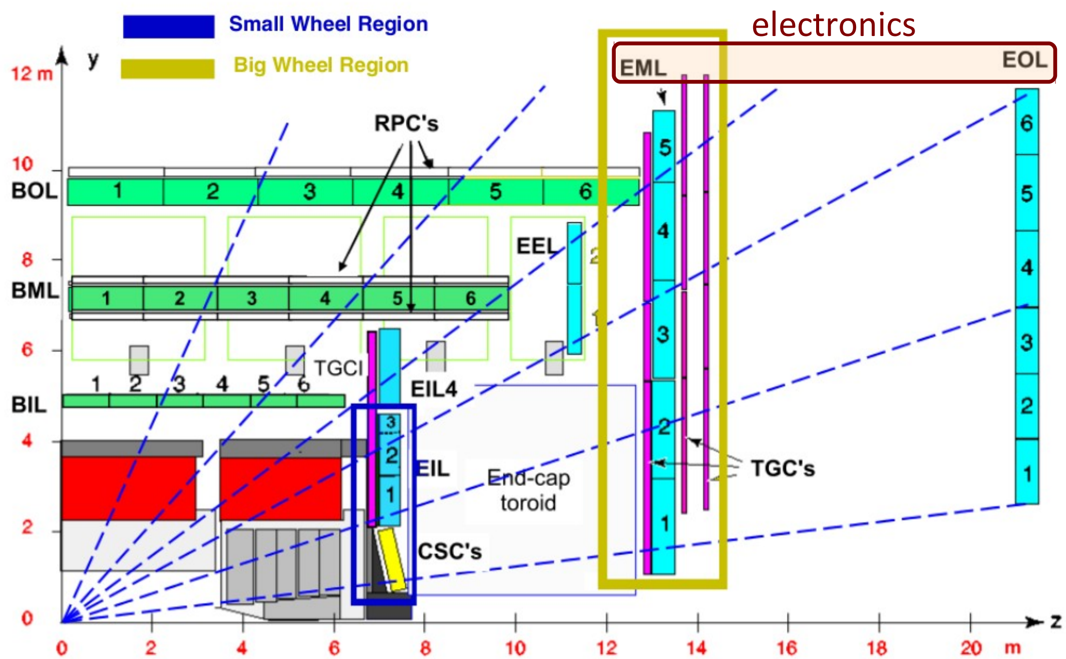
- Retain ability to trigger on jets at L0/L1: 35% of jet energy in TileCal
- Measure missing E_T at high occupancy: also at trigger
- More robust/reliable system: increased radiation dose

Phase II TileCal: US Involvement

Activity	R	U	S	I	Comments
Front End boards	X			X	• US built & maintains current FEB • long & unique experience with system
Main Board	X	X		X	• US built & maintains current Main Board • long & unique experience with system
LVPS	X	X		X	• US redesigned current LVPS system • uniquely qualified for Phase II work
Detector Control Systems					• many US TileCal DCS experts

Phase II Muon System

ATLAS
Muon System



❖ Phase II Muon Goals

- Maintain L1 threshold at 20 GeV at 40 kHz
- Reduce rate of fake high p_T trigger muons to < 10%
- Improve trigger p_T resolution by 25-30% in endcap

Phase II Muons: US Involvement

Activity	R	U	S	I	Comments
Endcap MDT CSMs		X			• US designed, built & maintains current CSMs • long & unique experience with system
CSM Cables					• part of the CSM project
Endcap MDT Mezzanines		X		X	• US designed & built current mezzanines
MDT Mezzanine ASIC	X	X		X	• US designing ASIC for Phase I NSW • will adapt that ASIC for Phase II

Phase II R&D and Next Steps

❖ R&D Activities in the US

Tracker	Pixels Strips	• Readout IC (RD53), low mass composites, module assembly, high speed readout, sensors, new technologies (rad hard CMOS, monolithic CMOS pixel chip,...) • Thermal mechanical cores, bus tapes, laminations, high thermal conductivity C materials, module & stave assembly & test, power, trigger features of IC
Calorimeters	LAr Electr. FCAL TileCal	• LAr electronics in Phase I - preamp/shaper ASIC, 16-bit ADC, 10 Gbps optical link **[NSF MRI]** • System-On-Chip ASIC for digital part of FE board • Effects of HL-LHC environment on LAr FCAL - Positive Ion Buildup, pulse degradation with radiation, + minor R&D projects • ongoing R&D for all aspects of US effort - FE boards, Main board, Low Voltage & POL reg, HV opto-boards, sROD, DCS - simulation, beam tests, radiation testing
Muons	Electronics	• BNL ASIC being developed for Phase I MicroMegas can be adapted for Phase II • preliminary studies of new Chamber Service Module
TDAQ	Trigger DAQ	• L1Calo work for Phase I • Generic readout system R&D at SLAC

❖ Next steps for Phase II

- TDRs: Pixels & Strips (2016); Calorimeters, Muons TDAQ (2017)

US Phase II Project: Cost & Effort

- Phase II Costs based on ATLAS Phase II LoI
  - ATLAS-wide bottom-up determination of core costs per sub-system

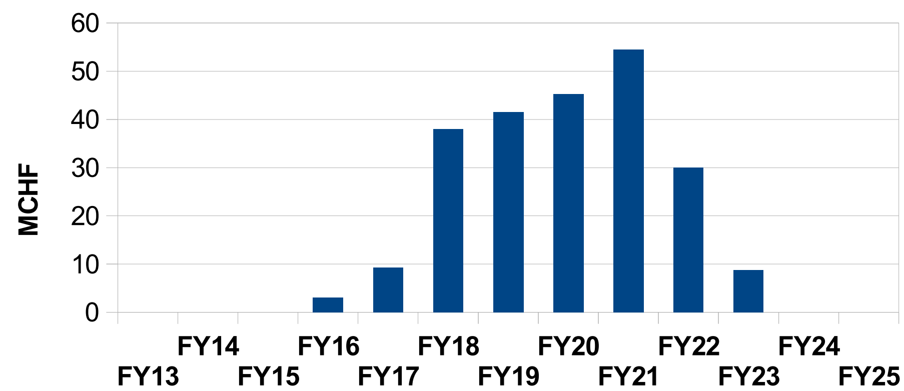
- Translating to Phase II US costs
  - determine core costs of US deliverables from LoI list
  - scale core costs → total costs using past experience
    - silicon: Total (no contingency) / M&S from US Original Construction
    - others: Total (no contingency) / M&S from US Phase I by sub-system
  - add Common (from Phase II LoI) and Project Management (scaled from Phase I) costs
  - add 50% contingency
  - total cost profile from sub-system bottom-up estimates

- Phase II Effort
  - Technical (on-project) effort: included in scaling above
  - Physicist (off-project) effort: bottom-up estimate for each Phase II sub-system
    - **~50 FTE physicists per year** – FLAT profile within 10% during construction project
    - note: this fits within 2013 physicist effort on Upgrade R&D + Construction (62 FTE)

US Phase II Project Cost Estimate

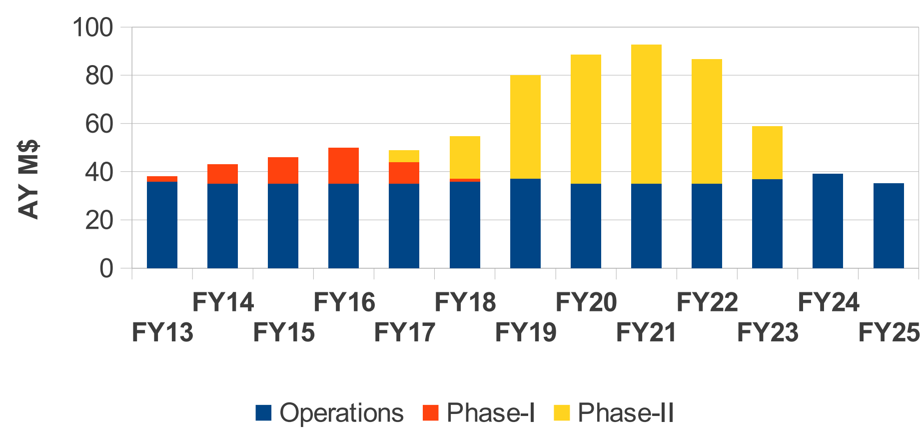
System	ATLAS core (FY12 MCHF)	US Core (AYM$)	US Total (AYM$)
Tracker	157.5	20.9	42.8
LAr	47.2	11.9	42.5
TileCal	10.0	3.4	12.0
Muons	20.1	1.6	3.5
TDAQ	24.2	7.3	51.9
Common Costs	16.3	4.0	4.0
Base Project Cost	*275.3*	*49.1*	*156.7*
Proj. Management			10.0
Contingency (50%)		24.6	83.4
TOTAL COST	**275.3**	**73.7**	**250.1**
Physicist FTE/year			**50**

ATLAS Phase II Core Cost Profile*



*shifted by 1 year with respect to LoI

US ATLAS Total Cost Profile



Benefits to US Infrastructure

- National Lab Facilities critical to ATLAS & CMS upgrades
  - ATLAS participating labs: ANL, BNL, FNAL, LBNL, SLAC
    - example facilities: LBNL Composites Fabrication Facility, SLAC test beam, electronics design/fab (all labs)
  - CMS participating labs: FNAL (their primary Energy Frontier project)
    - example facilities: FNAL SiDet, FNAL test beam, FNAL Electrical Engineering Dept.
  - Irradiation facilities: BNL-CO60, Indiana Cyclotron, FNAL-M03, LANL-LANSCE, LBNL, Dupage & Mass Gen Hospitals

- Heavy use of University Technology Infrastructure
  - clean rooms & silicon fabrication, many strong electronics design facilities
  - ties to mechanical and electrical engineering departments
  - excellent training ground for students and postdocs
    - current US grad students: 214 (ATLAS), 247 (CMS)

- Partnerships with US Industry (some examples)
  - ATLAS: Allcomp Inc. (high thermal conductivity foams), Reflex Photonics (rad tolerant optical transceivers), Berkeley Design Automation (circuit simulation tools)
  - CMS: Microsemi (rad-tolerant FPGAs), Tezzaron (3D ICs), Momentive Performance Materials Inc (thermally annealed pyrolitic graphite)

Conclusions

- Clear case for Phase-II ATLAS upgrades
  - strong physics case + LHC environment ==> detector requirements

- Major upgrades to both ATLAS & CMS
  - ATLAS: Tracker, Trigger/DAQ, Forward Calorimeter, Electronics for LAr Calo, Muons
  - CMS: Tracker, Trigger/DAQ, Endcap Calorimeters, Forward Muon System, Electronics
  - meet physics requirements as cost-effectively as possible
  - CERN Council endorsement of European Strategy for Particle Physics ==> CERN/Int'l HEP will proceed with LHC & detector upgrades

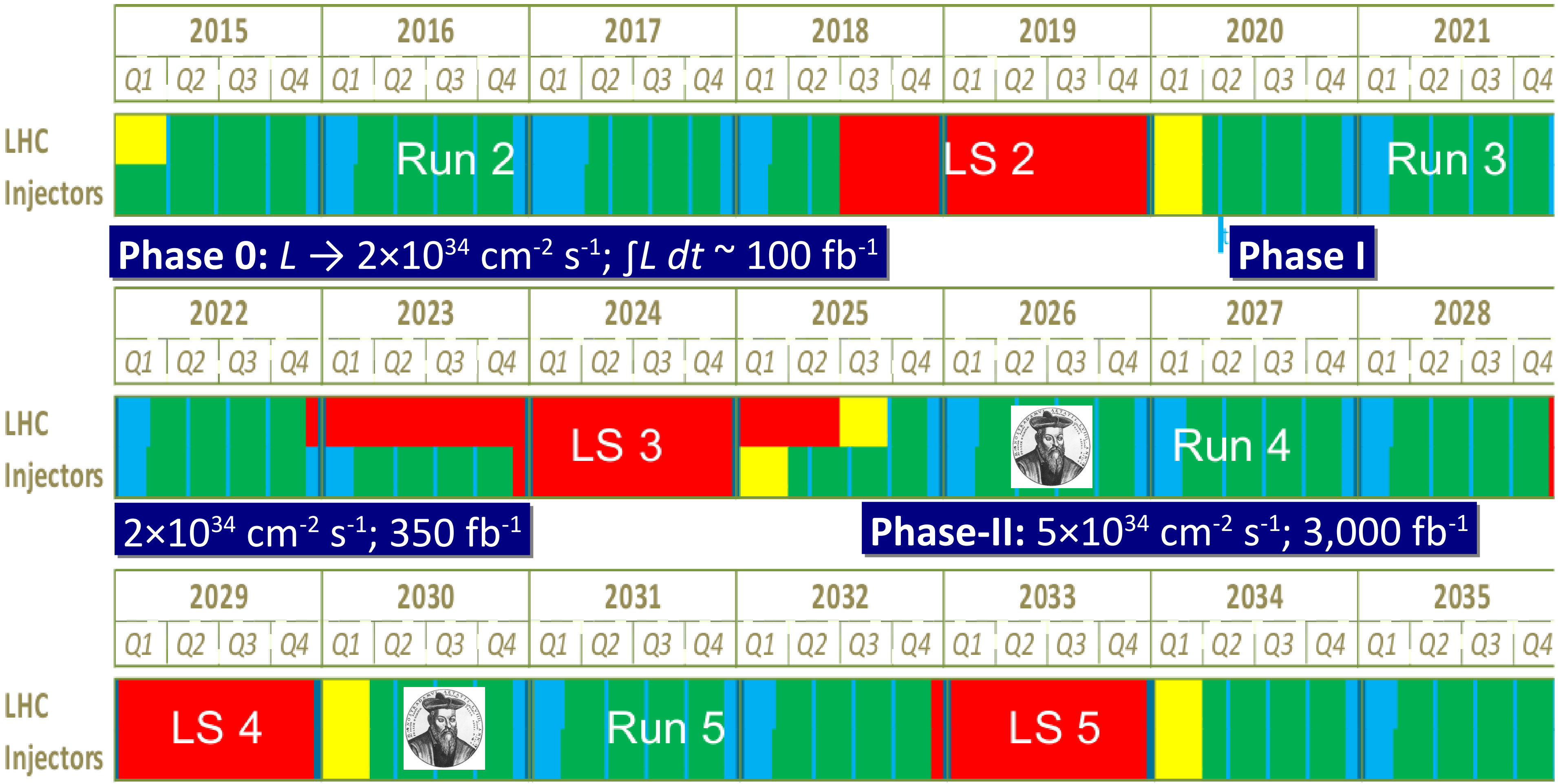
- US contributions target areas of special US expertise
  - no plans to expand US scope significantly
  - build upon/enhance cutting-edge technology infrastructure at labs, universities, industry

- Preliminary Phase-II US cost & effort
  - ATLAS: $250M, CMS: $270M
  - physicist FTE required to mount the upgrades fits within existing upgrade + Phase I effort

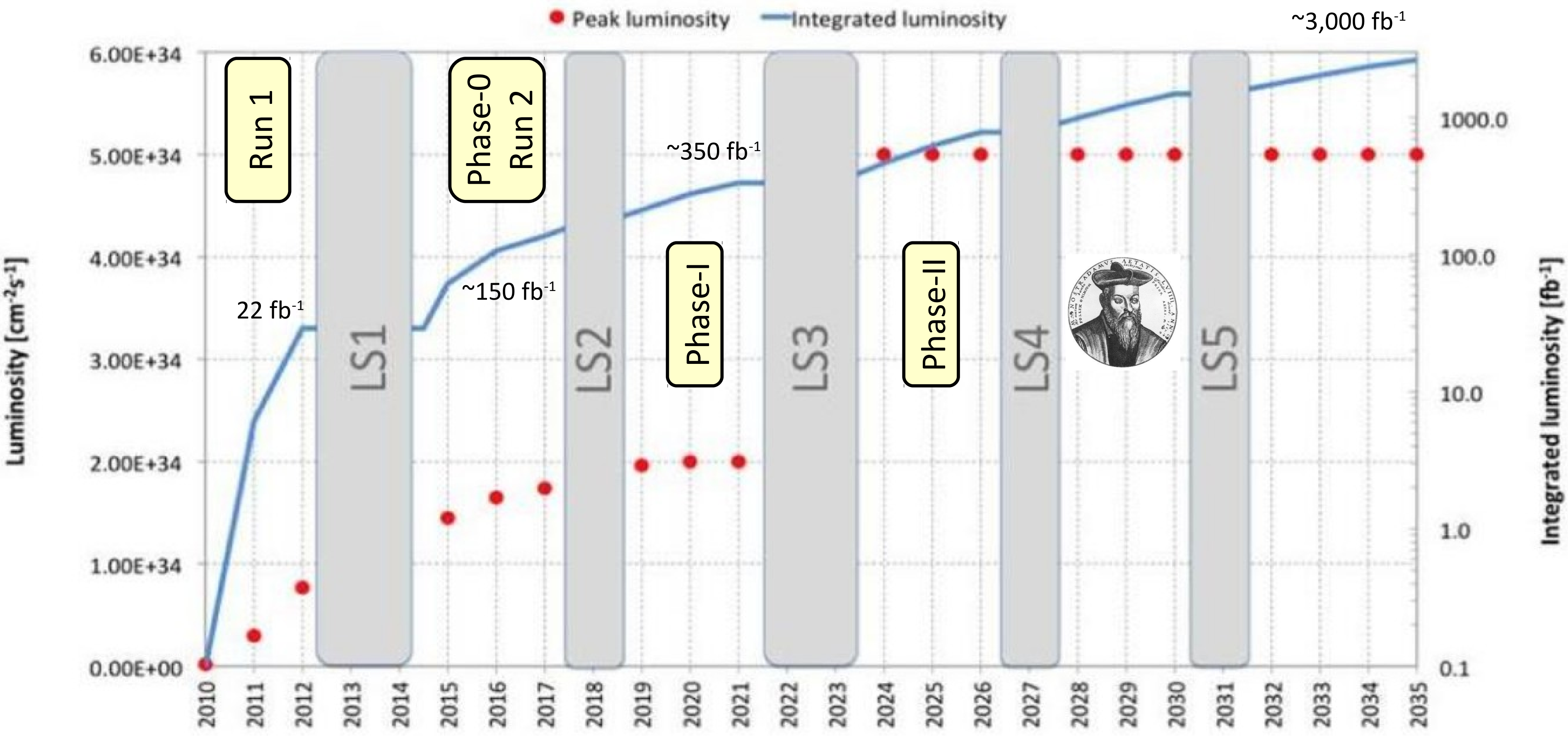
- US participation is critical to the success of ATLAS & CMS in Phase II
  - important to maintain our position as a reliable partner in international collaborations

BACKUP

New LHC Timeline

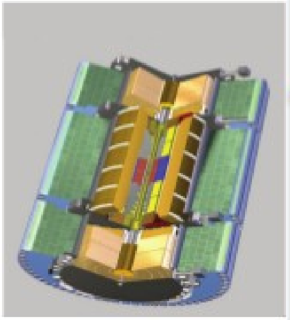


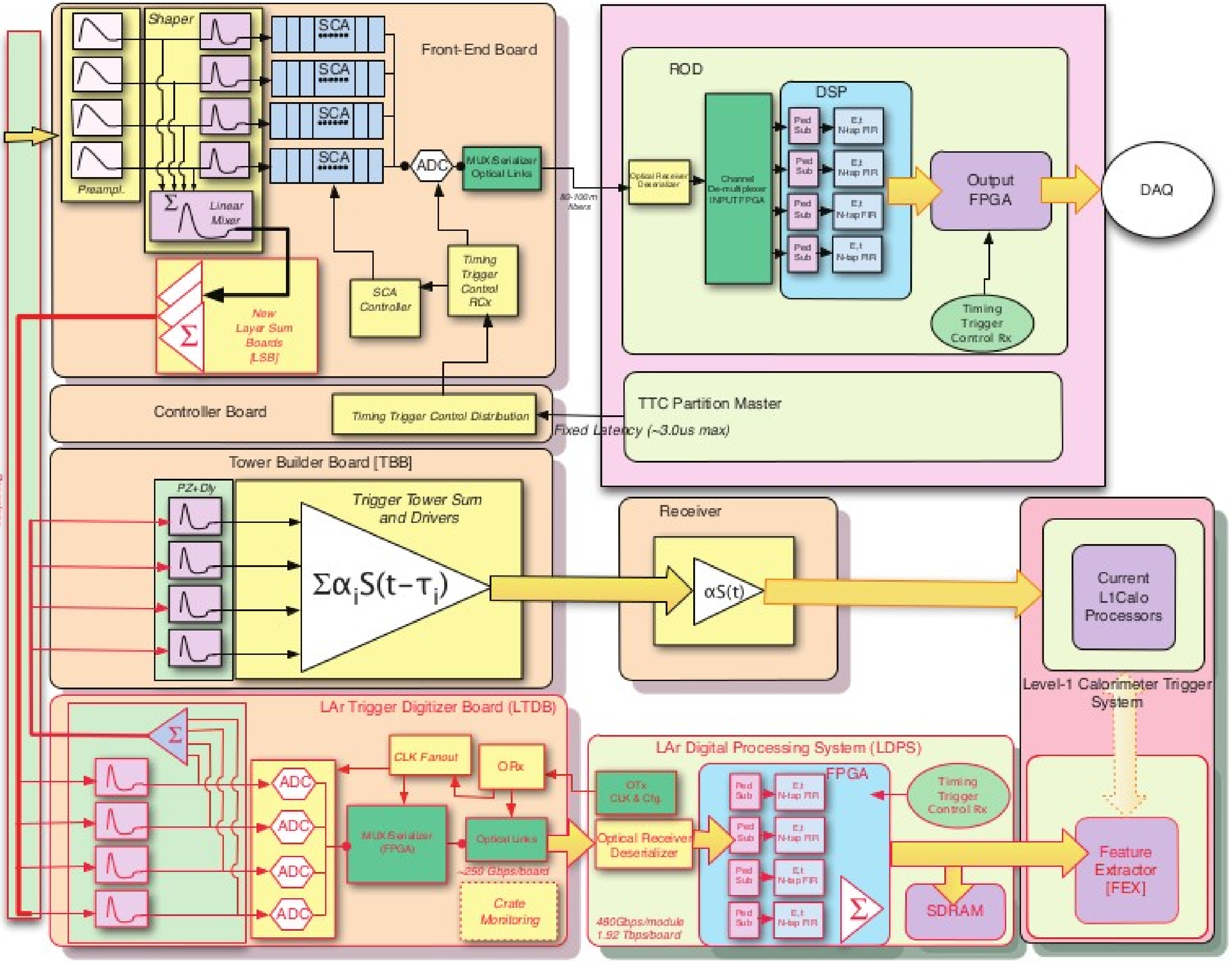
Previous LHC Timeline



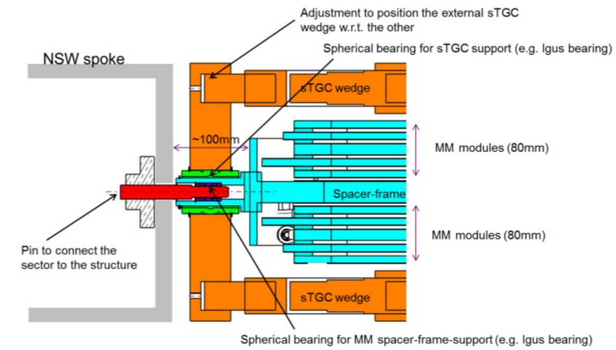
M.Lamont, 27 July 2013

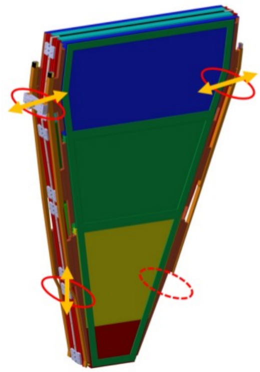
LAr in Phase I

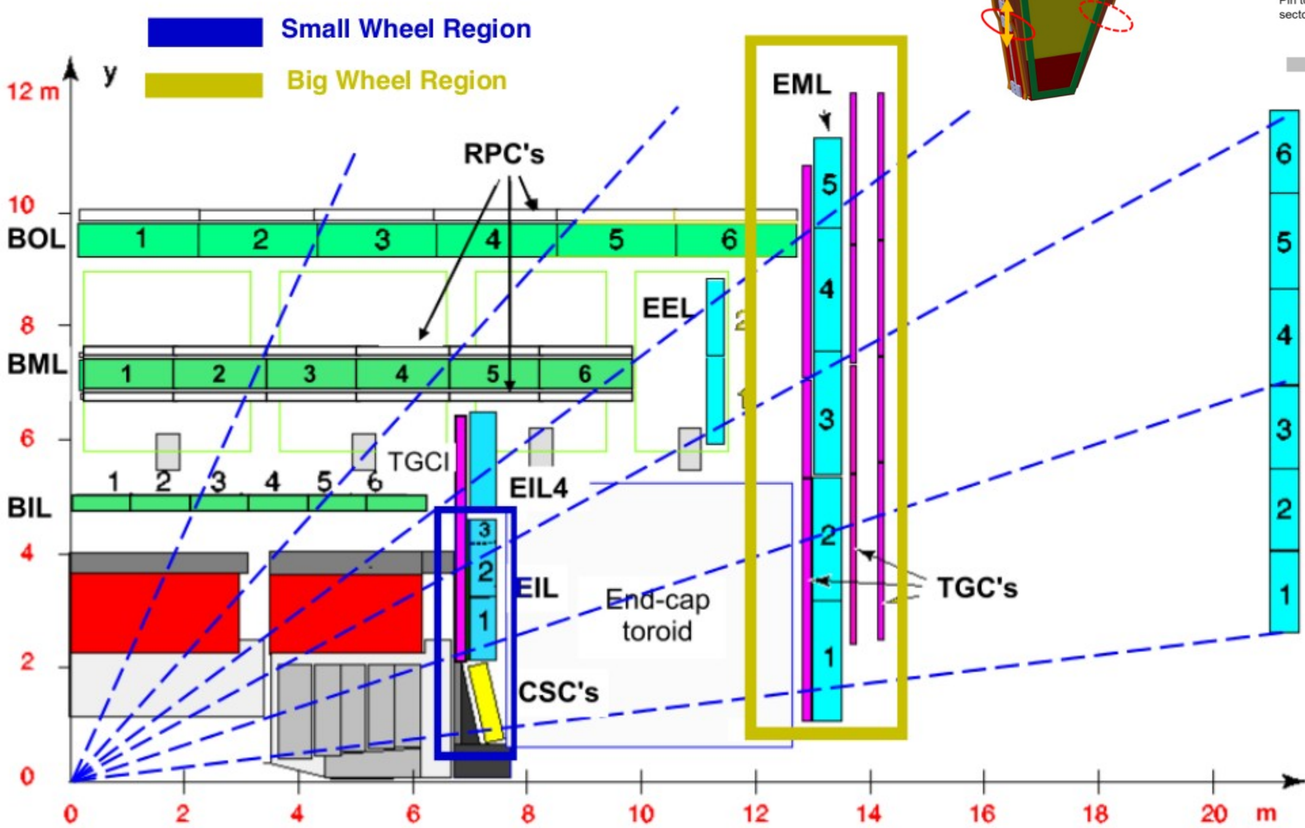


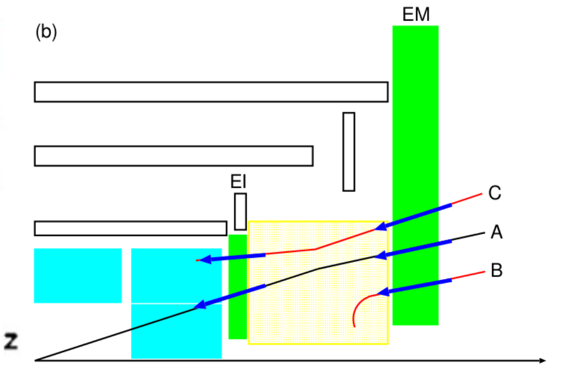


NSW in Phase I



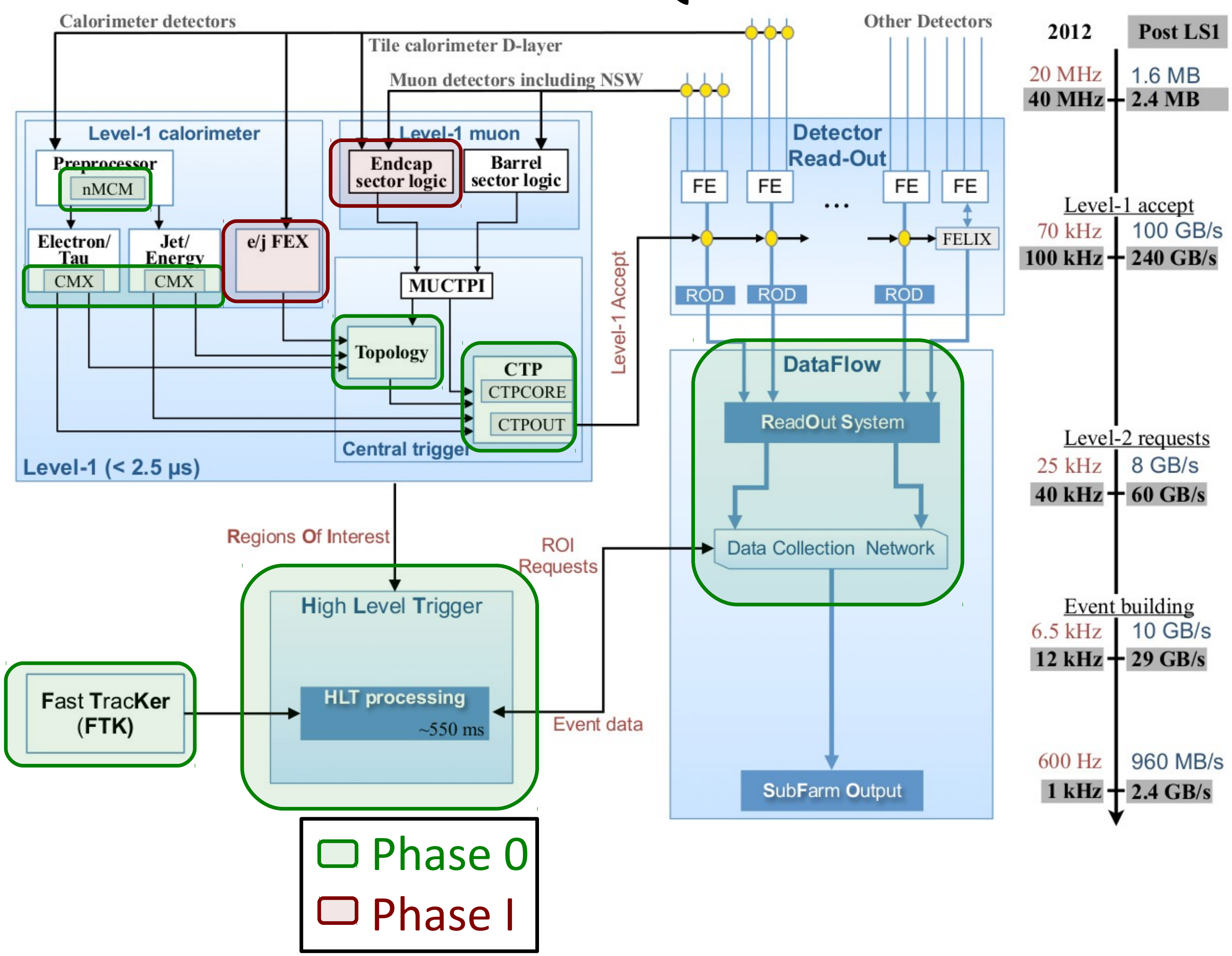




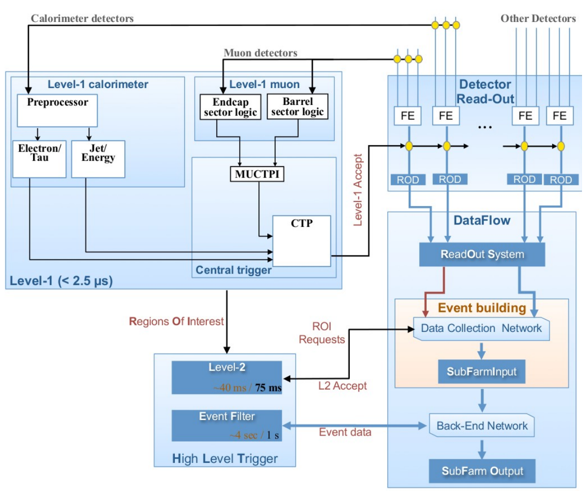


TDAQ Evolution: 2012 → Phase I

TDAQ in Phase I



TDAQ in 2012



TDAQ Thresholds

	Run 1			Run 2			Run 3	
	Threshold [GeV]	Rate [kHz]		Threshold [GeV]	Rate [kHz]		Threshold [GeV]	Rate [kHz]
EM18HV	24	130	EM30VHI	35	14	EM25VHR	30	14
EM30	35	61	EM80	100	2.5	EM80	100	2.5
2EM10	2x15	168	2EM20VH	2x25	3.4	2EM20VH	2x25	3.4
			2EM15VHI	2x20	2.9	2EM12VHR	2x17	5.0
EM total		**270**			**20**			**20**
MU15	25	82	MU20	25	26	MU20	25	12
2MU10	2x12	14	2MU11	2x14	4	2MU11	2x14	4
Muon total		**96**			**30**			**16**
EM10VH_MU6	15,6	22	EM15VH_MU10	20,14	3.0	EM10VHR_MU10	15,14	3
			EM10H_2MU6	15,2x6	2.5	EM10HR_2MU6	15,2x6	1.0
TAU40	100	52	TAU80V	180	4.7	TAU80VR	180	3.2
			2TAU50V	2x110	3.8	2TAU40VR	2x100	3.9
2TAU11I_TAU15	30,45	147	2TAU20VI_3J20	2x50,60	5.2	2TAU15R_3J15	2x40,50	8.1
2TAU11I_EM14VH	30,20	60	2TAU20VI_ EM20VHI_3J20	50,25,60	2.0	2TAU15R_ EM15HR_3J15	40,20,50	2.0
			TAU15VI_MU15	40,20	3.8	TAU11VR_MU15	35,20	3.6
TAU15_XE35	40,80	63	TAU20VI_XE40_3J20	50,90,60	4.4	TAU15VR_XE40_3J15	40,90,60	5.0
Tau total		**238**			**20**			**20**
J75	200	23	J100	250	7.0	J100	250	7.0
4J15	4x55	87	4J25	4x60	3.3	4J25	4x55	3.3
			J75_XE40	200,150	8.3	J75_XE40	200,150	8.3
XE40	120	157	XE90	250	4.5	XE80	200	5
Jet/E_T^{miss} total		**306**			**23**			**23**
Topological Triggers		**-**			**$\sim$ 10**			**$\sim$ 25**
Total		**$\sim$ 800**			**$\sim$100**			**$\sim$ 100**

$\sqrt{s}$=14 TeV, L=3×10^{34} (25ns)

US Phase I Org Chart

BNL Associate Laboratory Director
B. Mueller, ALD for NPP
D. Lissauer, Deputy

Project Office
J. Kotcher (BNL), Project Manager (PM)
C. Bee (Stony Brook), Deputy PM
J. Hobbs (Stony Brook), NSF Principal Investigator (PI)
ES&H Liaison - R. Gill (BNL)
QA Liaison - J. Eng (BNL)
Project Controls - C. Butehorn (BNL); X. Guo (BNL)
Project Administration – C. Kelly (Stony Brook); W. Yu (BNL)

WBS 1.1
LAr Cal Trigger Readout (LAr)
G. Brooijmans (Columbia)
J. Hobbs (Stony Brook), Deputy

- 1.1.1 Baseplanes — J. Rutherfoord (Arizona)
- 1.1.2 Layer Sum Boards (LSB) — J. Mueller (Pittsburgh)
- 1.1.3 LAr Trigger Digitizer Boards (LTDB) — M.-A. Pleier (BNL)
- 1.1.4 LAr Digital Processing System (LDPS) — S. Majewski (Oregon)
- 1.1.5 LAr Level 2 Project Management — G. Brooijmans (Columbia)

WBS 1.2
Muon New Small Wheel (nSW)
J. Bensinger (Brandeis)
V. Polychronakos (BNL), Deputy

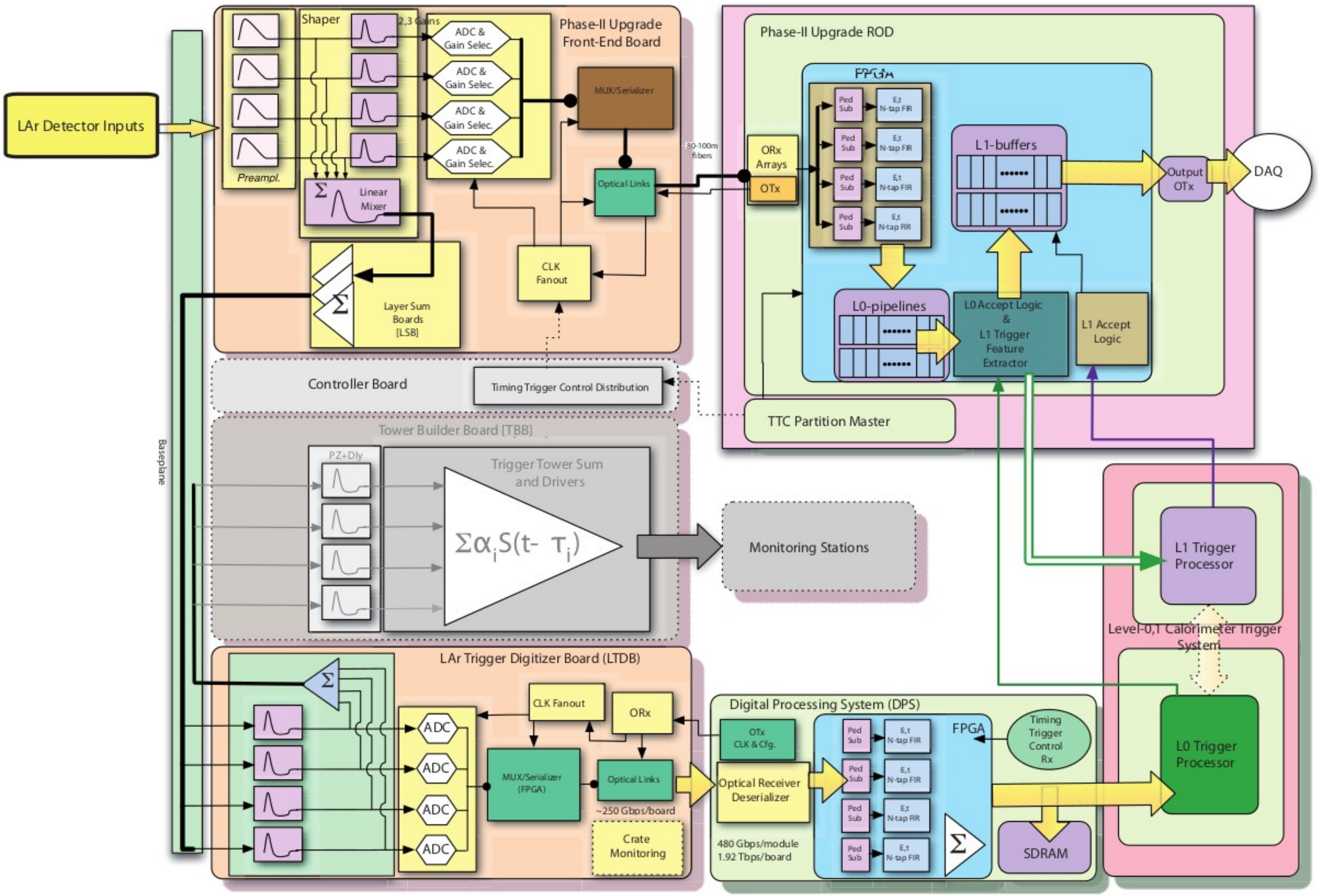
- 1.2.1 Micromegas (MM) Electronics — K. Johns (Arizona)
- 1.2.2 Alignment — C. Blocker (Brandeis)
- 1.2.3 Thin Gap Chambers (sTGC) Electronics — J. Zhu (Michigan)
- 1.2.4 nSW Level 2 Project Management — J. Bensinger (Brandeis)

WBS 1.3
Trigger/Data Acquisition (TDAQ)
C. Bee (Stony Brook)
H. Evans (Indiana), Deputy

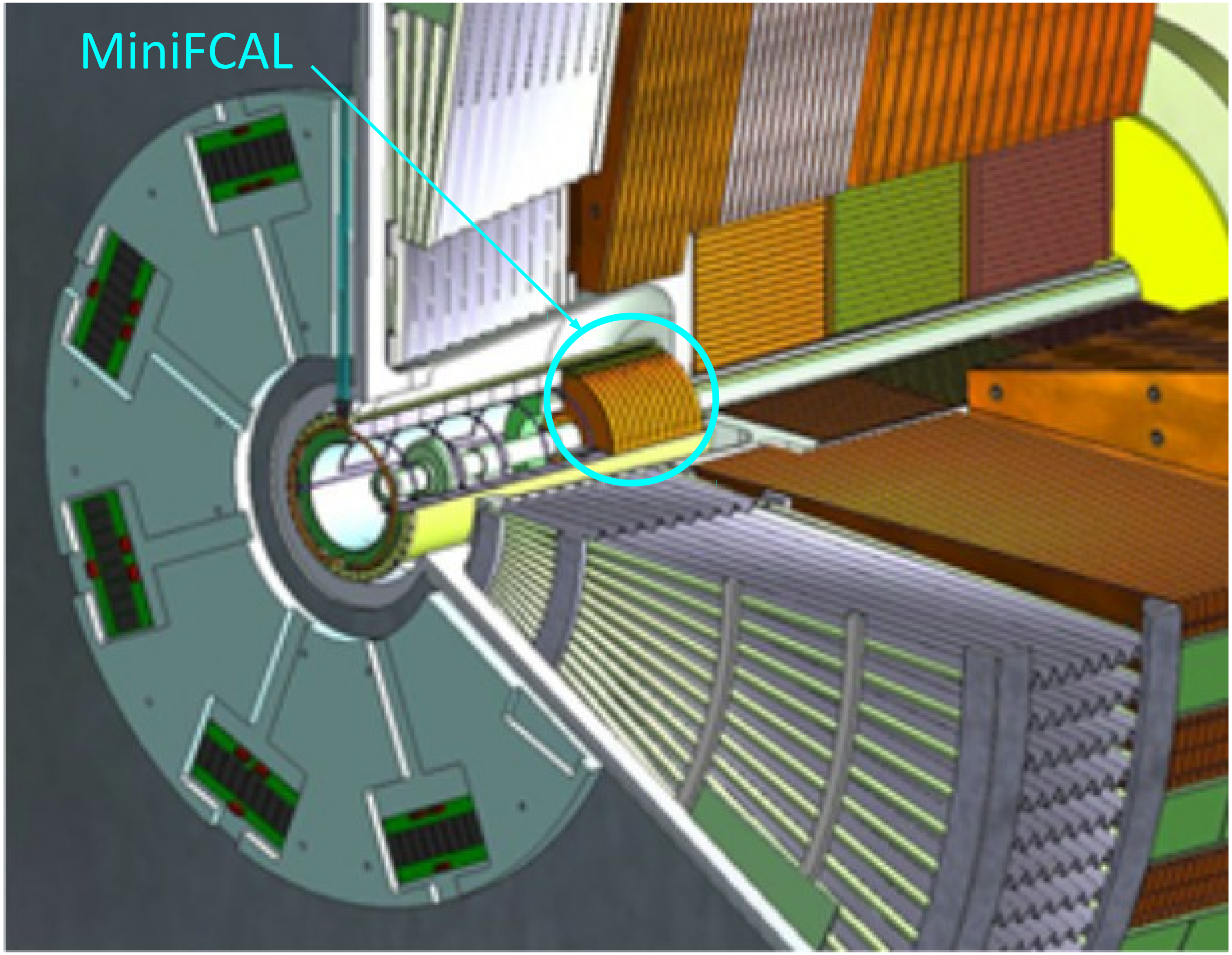
- 1.3.1 Readout Driver (ROD) & Algorithm Firmware — H. Chen (BNL)
- 1.3.2 FEX (Feature Extractor) ATCA Hub — W. Fisher (Michigan State)
- 1.3.3 e/jFEX Fiber Plant — R. Schwienhorst (Michigan State)
- 1.3.4 TDAQ Level 2 Project Management — C. Bee (Stony Brook)

WBS 1.4
Project Management
J. Kotcher (BNL)
Deputy, TBD

LAr Electronics in Phase II



FCAL in Phase II



US Phase II Project Schedule

	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026-2035
LHC		LS1		Run 2			LS2		Run 3			LS3		Run 4...
ATLAS Analysis														
ATLAS Operations														
Phase-I	preprod		construction			inst/comm								
Phase-II Pixels					preprod	construction					install/commiss			
Phase-II Strips					preprod	construction					install/commiss			
Phase-II LAr Electr							preprod	construction				inst/comm		
Phase-II FCAL							preprod	construction				inst/comm		
Phase-II TileCal					demonstrator/preprod				construction		install/commiss			
Phase-II Muons					preprod				construction		install/commiss			
Phase-II Trigger						preprod	construction				install/commiss			
Phase-II Readout					preprod	construction				commiss				

- Critical period: 2017-2018 (ops + Phase-I + Phase-II)
  - Tracker: little overlap between Phase-II work and Ops (no Phase-I)
  - LAr: Phase-II pre-production ramps up after critical period
  - TileCal: little overlap between Phase-II work and Ops (no Phase-I)
  - Muons: most groups do not have simultaneous Ph-I and Ph-II efforts
    - exception is BNL, which has a large pool of technical personnel
  - TDAQ: conflict limited to L0/L1Calo work at a few institutes
    - FTK operational before LS2
    - Readout effort ongoing independent of Phase

Core to Total Cost Scaling

❖ Scaling Used

Sub-system	Source	Core (AYM$)	Total (AYM$)	Scale
Silicon	original construction	12.26	25.13	2.05
Calorimeters	Phase I LAr	3.73	13.28	3.56
Muons	Phase I Muons	5.30	11.77	2.22
TDAQ	Phase I TDAQ	0.45	3.20	7.11

❖ Comparison of Original ATLAS/Phase I with Phase II projects

Sub-system	Phase	large unit count	small-moderate unit count
Silicon	original Phase II	sensors, modules modules, staves, ASICs	--- ---
LAr Electronics	Phase I Phase II	--- ---	Layer Sum Boards, Low Voltage Preamp/Shaper, ADC, optics ASICs
Muons	Phase I Phase II	ASICs MDT mezzanines & ASICs	MM Trigger & FE Boards CSMs
TDAQ	Phase I Phase II	--- ---	Hub modules, Fiber Plant processing boards

Physicist FTE by Sub-system

Sub-system	Physicist FTE/year
Pixels	14
Strips	16
LAr Electronics	5.8
LAr FCAL	1.0
TileCal	2.8
Muons	4.0
TDAQ	5.8
TOTAL	49.4

Industrial Partners

Partial list of companies we work with

Company	A/C	Products
Agilent	A/C	test equipment
Allcomp	A/C	low-mass high-conductivity carbon foam materials
Applicad	A	PCB assembly
Avago	A/C	opto links
Berkeley Design Automation	A	high speed circuit simulation tools
CADENCE	A/C	design tools
CASCADE	C	silicon sensor characterisation
CVI	C	bump-bonding 3D ICs, glass-based interposers
Electrotek	A	PCB fabrication
I2E	A/C	chip packaging
Luxtera	A	optical communications
MATERION	C	beam pipes
Mentor Graphics	A/C	design tools
Momentive Performance Materials	C	thermally annealed pyrolytic graphite (TPG)
MOSIS	A/C	chip fabrication
Quik-Pak	A	chip packaging
Reflex Photonics	A/C	opto links
Rhode & Schwartz	A	test equipment
RTI	C	silicon vias, bump bonding, & 3D vertical integration
Sygaris	C	wafer grinding, thinning, & dicing to 50 µm
Tezzaron	C	3D IC development & testing
Triangle Labs	A	PC board manufacture (ATLAS Micromegas)
Xilinx	A/C	FPGAs
Ziptronix	C	DBI oxide bonding of sensors & electronics